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(54) **FLEXIBLE FILM WITH SURFACE RELIEF AND USE THEREOF IN ELECTRO-ACTIVE OPTICAL SYSTEMS**

FLEXIBLE FOLIE MIT OBERFLÄCHENRELIEF UND VERWENDUNG IN ELEKTROAKTIVEN OPTISCHEN SYSTEMEN

FILM FLEXIBLE À SURFACE EN RELIEF ET SON UTILISATION DANS DES SYSTÈMES OPTIQUES ÉLECTRO-ACTIFS

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Description

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims the benefit of priority to U.S. Provisional Patent Application No. 61/587,260, filed January 17, 2012, U.S. Provisional Patent Application No. 61/728,940, filed November 21, 2012, and U.S. Provisional Patent Application No. 61/733,031, filed December 4, 2012.

FIELD OF THE INVENTION

[0002] The present invention relates generally to flexible thin films for use in electro-active optical systems. Embodiments of the invention include thin films having diffractive structures on at least one surface of the film, and methods of making such films. Embodiments of the invention also include lens blanks that comprise such thin films. Embodiments of the invention also include methods of making lens blanks that comprise such thin films.

BACKGROUND

[0003] US 2010/177408 A1 relates to micro-electrical-mechanical (MEMS) wafers in which a lens is formed on a micro-electrical-mechanical structure. The micro-electrical-mechanical wafers can comprise a substrate, MEMS structures, and a lens array. A method of forming a micro-electrical-mechanical wafer comprises providing a substrate, forming a micro-electrical-mechanical structure on the substrate, forming a carrier, forming a lens array on the carrier, and transferring the lens array from the carrier onto the micro-electrical-mechanical structure. The lens array is placed above the micro-electrical-mechanical structure.

[0004] Optically transparent thin films can be incorporated into various lens systems, and, in many instances, bear certain relief structures, such as diffractive structures. These relief structures can be etched or embossed onto the thin film, which means that forming the film and forming the relief structures requires at least two separate steps. These separate processing steps increases the time and effort required to make such films. Therefore, it may be desirable to develop a manufacturing process that allows the relief structures and the film to be formed simultaneously, thereby reducing the processing time and cost of making the film.

[0005] Further, such films are generally flat. In instances where it is desirable to fit the film over a curved surface (e.g., a convex or concave surface), the film can be stretched to fit the shape of the curved surface onto which the film is disposed. This stretching causes additional force to be exerted against the film, thereby making the film more susceptible to mechanical breakdown or mechanical failure. Therefore, it may be desirable to develop a film and a manufacturing process therefor, where the film is formed so as to have a shape that is substantially similar as that of the surface onto which it is to be disposed, thereby partially or completely alleviating the need to stretch the film over the curved surface.

[0006] Further, when such films are used in certain optical systems, such as an electro-active optical lens blanks, the films can be used to help seal the electro-active material into a cavity within the blank. Because the film may be under some degree of mechanical stress (described above), it can be difficult to dispose the electro-active material into the cavity while maintaining the necessary mechanical stress on the film. Therefore, it may be desirable to develop a simpler process for disposing the electro-active material within the cavity without risking disruption of the physical integrity of the film.

SUMMARY OF THE INVENTION

[0007] In an aspect, there is provided a method of making an electro-active system as defined in appended claim 1.

[0008] In at least one aspect, the invention provides methods of making a film having surface relief features, comprising: (a) providing a first substrate having a first surface, wherein the first substrate is composed of a water-soluble solid material; (b) providing a second substrate having a first surface, wherein the second substrate is composed of a solid material and the first surface of the second substrate comprises one or more relief structures; (c) providing a curable liquid material; (d) disposing the curable liquid material between the first surface of the first substrate and the first surface of the second substrate, wherein the first surface of the first substrate and the first surface of the second substrate are adjacent to each other; (e) curing the curable liquid material to form a polymeric film between the first surface of the first substrate and the first surface of the second substrate; and (f) exposing the first surface to an aqueous medium, thereby dissolving the first substrate.

[0009] In another aspect, the invention provides thin films, comprising: (a) a naturally curved first surface; and (b) a naturally curved second surface disposed opposite the naturally curved second surface, wherein the naturally curved second surface comprises one or more relief structures; wherein the naturally curved first surface is concave, and the naturally curved second surface is convex, and wherein the radius of curvature of the naturally curved first surface is within 15% of the radius of curvature of the naturally curved second surface.

[0010] In another aspect, the invention provides electro-active systems, comprising: (a) a curved substrate having a concave surface and a convex surface, wherein the concave surface is opposite the convex surface; (b) a thin film according to any of the embodiments described herein disposed on the concave surface of the curved substrate such that the naturally curved second surface of the thin film faces the concave surface of the curved substrate. In some further aspects, the invention provides lenses or lens blanks where such electro-active systems are disposed on the lenses or lens blanks.

[0011] In another aspect, the invention provides methods of making an electro-active system, comprising: (a) providing a curved substrate having a concave surface and a convex surface, wherein the concave surface is opposite the convex surface; (b) providing a thin film of any of the embodiments described herein; (c) securing the thin film to the curved substrate such that the naturally curved second surface of the thin film faces the concave surface of the curved substrate and forms a sealed cavity between the thin film and the curved substrate; and (d) injecting an electro-active material into the sealed cavity via an injection site in the thin film. In some further aspects, the invention provides methods of making lenses or lens blanks comprising making an electro-active system, and disposing the electro-active system on lenses or lens blanks.

[0012] Further aspects and embodiments of the invention are provided in the detailed description that follows and in the accompanying figures.

BRIEF DESCRIPTION OF DRAWINGS

[0013] The application includes the following figures. These figures depicts certain illustrative embodiments of various aspects of the invention. The figures are not intended to limit the scope of the claimed subject matter apart from an express indication to the contrary.

Figure 1 depicts a stage of the method of making the thin film after the liquid curable material has been disposed between the first and second substrates and before removal of either substrate.

Figure 2 depicts a stage of the method of making the thin film after the liquid curable material has been disposed between the first and second substrates and before removal of either substrate.

Figure 3 depicts a flexible thin film having a naturally flat shape.

Figure 4 depicts a flexible thin film having a naturally curved shape.

Figure 5 depicts a flow diagram for a method of making a flexible thin film.

Figure 6 depicts a flow diagram for a method of making a flexible thin film.

Figure 7 depicts an electro-active system.

Figure 8 depicts a flow diagram for a method of making an electro-active system.

Figure 9 depicts an electro-active system disposed on an optical substrate.

Figure 10 depicts a flow diagram for a method of making an optical substrate having an electro-active system.

DETAILED DESCRIPTION

[0014] The following description recites various aspects and embodiments of the present invention. No particular embodiment is intended to define the scope of the invention. Rather, the embodiments merely provide non-limiting examples various compositions, apparatuses, and methods that are at least included within the scope of the invention. The description is to be read from the perspective of one of ordinary skill in the art; therefore, information well known to the skilled artisan is not necessarily included.

[0015] As used herein, the articles "a," "an," and "the" include plural referents, unless expressly and unequivocally disclaimed.

[0016] As used herein, the conjunction "or" does not imply a disjunctive set. Thus, the phrase "A or B is present" includes each of the following scenarios: (a) A is present and B is not present; (b) A is not present and B is present; and (c) A and B are both present. Thus, the term "or" does not imply an either/or situation, unless expressly indicated.

[0017] As used herein, the term "comprise," "comprises," or "comprising" implies an open set, such that other elements can be present in addition to those expressly recited.

[0018] Unless otherwise indicated, all numbers expressing quantities of ingredients, reaction conditions, and so forth used in the specification are to be understood as being modified in all instances by the term "about." Accordingly, unless indicated to the contrary, the numerical parameters set forth in the following specification are approximations that can vary depending upon the desired properties sought to be obtained by the present invention. At the very least, and not as an attempt to limit the application of the doctrine of equivalents to the scope of the claims, each numerical parameter should at least be construed in light of the number of reported significant digits and by applying ordinary rounding techniques.

[0019] Notwithstanding that the numerical ranges and parameters setting forth the broad scope of the invention are approximations, the numerical values set forth in the specific examples are reported as precisely as possible. Any numerical value, however, inherently contains certain errors necessarily resulting from the standard deviation found in their respective testing measurements. Moreover, all ranges disclosed herein are to be understood to encompass any and all subranges subsumed therein. For example, a stated range of "1 to 10" should be considered to include any and all subranges between (and inclusive of) the minimum value of 1 and the maximum value of 10; that is, all subranges beginning with a minimum value of 1 or more, e.g. 1 to 6.1, and ending with a maximum value of 10 or less, e.g., 5.5 to 10.

[0020] In at least one aspect, the invention provides methods of making a film having surface relief features, comprising: (a) providing a first substrate having a first surface, wherein the first substrate is composed of a water-soluble solid material; (b) providing a second substrate having a first surface, wherein the second substrate is composed of a solid material and the first surface of the second substrate comprises one or more relief structures; (c) providing a curable liquid material; (d) disposing the first surface of the first substrate adjacent to the first surface of the second substrate, and disposing the curable liquid material between the first surface of the first substrate and the first surface of the second substrate; (e) curing the curable liquid material to form a polymeric film between the first surface of the first substrate and the first surface of the second substrate; and (f) exposing the first surface to an aqueous medium, thereby dissolving the first substrate.

[0021] The first substrate is a substrate that has a first surface and is composed of a solid material that is soluble in water or other aqueous media. The first surface can have any acceptable texture. In some embodiments, the surface is a surface that is generally smooth or even. The first substrate is composed of a solid material that is soluble in water or other aqueous media. In this context, the term "soluble" does not necessarily imply that every molecule of the solid necessarily solubilizes an aqueous medium. Rather, in this context, the term implies that the solid material loses its internal structural integrity when exposed to an aqueous medium. For example, in some embodiments, the water soluble solid material refers to a solid material that, when exposed to an aqueous medium, loses its internal structural integrity and can therefore be washed away by exposing it to water or other aqueous media. The invention is not limited to any particular such material. For example, in some embodiments, the water soluble solid material is an inorganic material, including, but not limited to, metal oxides, such as silica, alumina, or titania. In some other embodiments, the water soluble solid material is a water soluble polymer, including, but not limited to polyvinyl alcohol, a polyacrylamide, a polyacrylic acid (e.g., polyacrylic acid or partially esterified derivatives thereof), a polyisocyanate, a starch, or a cellulose (e.g., carboxymethylcellulose, hydroxymethylcellulose, etc.). In some embodiments, the water soluble solid material is polyvinyl alcohol.

[0022] The first surface of the first substrate can have any desired shape. In some embodiments, the first surface of the first substrate is a flat surface. In some other embodiments, the first surface of the first substrate is a curved surface, such as a convex or concave surface. In some embodiments, the first surface of the first substrate is a convex surface. In embodiments where the first surface of the first substrate is a curved surface, the surface can have any suitable radius of curvature, depending on the desired curvature of the resulting thin film.

[0023] In some embodiments, the first surface of the first substrate is at least partially coated with an agent that can facilitate release of the thin film from the surface following the curing. In some embodiments, this agent is a surface release agent. In some other embodiments, the agent is polyvinyl alcohol.

[0024] The second substrate is a solid substrate having a first surface that comprises one or more relief structures. The first surface of the second substrate can have any desired shape. In some embodiments, the first surface of the second substrate is a flat surface. In some other embodiments, the first surface of the second substrate is a curved surface, such as a convex or concave surface. In some embodiments, the first surface of the second substrate is a concave surface. In embodiments where the first surface of the second substrate is a curved surface, the surface can have any suitable radius of curvature, depending on the desired curvature of the resulting thin film.

[0025] In some embodiments, the first surface of the first substrate is a convex surface, and the first surface of the second substrate is a concave surface. In some such embodiments, the two curved surfaces have similar radii of curvature, for example the radius of curvature of the first surface of the first substrate is within 1%, or 2%, or 3%, or 5%, or 7%, or 10%, or 15%, or 20% of the radius of curvature of the first surface of the second substrate.

[0026] The first surface of the second substrate comprises one or more relief structures. In some embodiments, the first surface of the second substrate comprises a plurality of relief structures, for example from 2 to 500, or from 5 to 200, or from 10 to 100 relief structures. The relief structures can be formed in any suitable way, e.g., by any suitable combination of recesses and extensions from the plane of the surface. In some embodiments, the relief structures are inverted diffractive structures. The relief structures can be of any suitable size and shape. In some embodiments, the relief structures have a height ranging from 1 nm to 3 mm, or from 1 nm to 2 mm, or from 1 nm to 1 mm, or from 1 nm to 500 μm, or from 10 nm to 500 μm, or from 100 nm to 500 μm, or from 1 μm to 500 μm. In embodiments where the surface comprises a plurality of relief structures, the relief structures can be separated by any suitable distance. In some embodiments, one or more pairs of adjacent relief structures are separated by a distance ranging from 1 nm to 3 mm, or from 1 nm to 2 mm, or from 1 nm to 1 mm, or from 1 nm to 500 μm, or from 10 nm to 500 μm, or from 100 nm to 500 μm, or from 1 μm to 500 μm.

[0027] The invention is not limited to any particular curable liquid material. In some embodiments, the curable liquid material comprises an organic material. In some such embodiments, the curable liquid material comprises a monomers, oligomers, or a mixture thereof. In some embodiments, the curable liquid material is a thermally curable resin, which can be cured by heat to form a solid or semi-solid material. Thermally curable resins are well known to those of skill in the art, and include, but are not limited to silicones, polyamides, polyurethanes, and epoxy resins. In some other embodiments, the curable liquid material is cured by intense electron beam (EB-cured resin). In some other embodiments, the curable liquid material is a photo-curable resin, such as a UV-curable resin. Photo-curable resins are well known to those of skill in the art and include, but are not limited to, acrylic resins, urethane resins (e.g., thiourethane resins), epoxy resins, or any mixtures thereof. In some embodiments, the photo-curable resin comprises an acrylic resin. In some other embodiments, the photo-curable resin comprises a thiourethane resin. Various commercially available photo-curable resins can also be used, such as DOUBLEMER resins DYMAX resins, SARTOMER resins, RADCURE resins, Shikoh UV-curable resins (by Nippon Gohsei), Nippon Kayaku resins, and the like.

[0028] The method includes disposing the curable liquid material between the first surface of the first substrate and the first surface of the second substrate, wherein the first surface of the first substrate and the first surface of the second substrate are adjacent to each other. The two substrate surfaces can be separated by any suitable distance, depending on the desired thickness of the thin film. In some embodiments, the surfaces of the two substrates are separated by a distance ranging from 1 μm to 1 mm, or from 10 to 500 μm, or from 50 to 200 μm. The resulting size of the film can be controlled by adjusting the volume of the curable liquid material disposed between the two surfaces. In some embodiments, the curable liquid material fills the space between the two substrate surfaces along at least a portion of the surfaces. In some embodiments, the curable liquid material fills the space between the two substrates in the location where the first surface of the second substrate bears one or more relief structures.

[0029] The method includes curing the liquid curable material, so as to form a solid or semi-solid polymeric film. The curing can be carried out in any suitable way, depending on the composition of the curable liquid material. In some embodiments, the curing comprises heating the liquid curable material. In some embodiments, the curing comprises exposing the liquid curable material to light, such as ultraviolet light. In some embodiments, the resulting polymeric film is transparent, meaning that it transmits at least 75%, or at least 80%, or at least 85%, or at least 90%, or at least 95%, or at least 97%, or at least 99% of visible light.

[0030] The method includes removing the first substrate from the polymeric film. In some embodiments, this removing comprises exposing the first substrate to an aqueous medium, such as water. This exposing can be done in any suitable manner. For example, in some embodiments, the first substrate is sprayed or squirted with a stream of an aqueous medium so as to break down the water-soluble solid material. In some other embodiments, the first substrate is dipped into a bath containing an aqueous medium.

[0031] In some embodiments, the method includes removing the polymeric film from the second substrate. In some such embodiments, this removing comprises physically separating the polymeric film from the second substrate. In some embodiments, the first surface of the second substrate is at least partially coated with a surface release agent, thereby facilitating the physical removal process. In some other embodiments, the removing comprises exposing the interface of the polymeric film and the first surface of the second substrate to an aqueous medium, such as water. In some embodiments, the first surface of the second substrate is coated with a thin layer of a water-soluble material, such as polyvinyl alcohol. When the interface is exposed to an aqueous medium, the water-soluble material breaks down and the film is released. This exposing can be done in any suitable manner. For example, in some embodiments, the interface region is sprayed or squirted with a stream of an aqueous medium so as to break down the water-soluble material. In some other embodiments, the second substrate and the film are dipped into a bath containing an aqueous medium. In some embodiments, the first substrate, the second substrate, and the polymeric film are all dipped into an aqueous medium at one time.

[0032] The methods described above need not be carried out in a manner in which only a single film is made. Thus, in some embodiments, the method is carried out in a batched process where 2 to 500, or 2 to 250, or 2 to 100, or 2 to 50, or 2 to 25 films are made simultaneously.

[0033] Figure 1 depicts the method at a stage after the curable liquid material has been added and before removal of the substrates. The diagram shows the first substrate 101 and the second substrate 102, where the second substrate has relief features 104. Between the two substrates lies the curable liquid material. In some other embodiments, the cured thin film 103 lies between the two substrates. Figure 2 depicts the same, except that the surfaces of the substrates are curved instead of flat. The drawing depicts the first substrate 201, the second substrate 202 having the relief features 204. In some embodiments, the curable liquid material 203 lies between the two substrates. In some other embodiments, the cured thin film 203 lies between the two substrates.

[0034] Figure 5 depicts a flow chart for one embodiment of the invention. In such embodiments, the method includes: (a) providing a first substrate having a first surface, wherein the first substrate is composed of a water-soluble solid material 501; (b) providing a second substrate having a first surface, wherein the second substrate is composed of a solid material and the first surface of the second substrate comprises one or more relief structures 502; (c) providing a curable liquid material 503; (d) disposing the first surface of the first substrate adjacent to the first surface of the second substrate, and disposing the curable liquid material between the first surface of the first substrate and the first surface of the second substrate 504; (e) curing the curable liquid material to form a polymeric film between the first surface of the first substrate and the first surface of the second substrate 505; and (f) exposing the first surface to an aqueous medium, thereby dissolving the first substrate 506.

[0035] Figure 6 depicts an alternate embodiment, which includes the steps of: (a) providing a first substrate having a first surface, wherein the first substrate is composed of a water-soluble solid material 601; (b) providing a second substrate having a first surface, wherein the second substrate is composed of a solid material and the first surface of the second substrate comprises one or more relief structures 602; (c) providing a curable liquid material 603; (d) disposing the first surface of the first substrate adjacent to the first surface of the second substrate, and disposing the curable liquid material between the first surface of the first substrate and the first surface of the second substrate 604; (e) curing the curable liquid material to form a polymeric film between the first surface of the first substrate and the first surface of the second substrate 605; (f) exposing the first surface to an aqueous medium, thereby dissolving the first substrate 606; and (g) removing the polymeric film from the second substrate 607. In some embodiments, one can obtain, among other embodiments, a thin film such as that depicted in Figures 3 or 4. Figure 3 shows a flat film 301 having relief structures 302 not falling under the scope of the invention.

[0036] Figure 4 shows a naturally curved film 401 having relief structures 402. In another aspect, the invention provides thin films, comprising: (a) a naturally curved first surface; and (b) a naturally curved second surface disposed opposite the naturally curved second surface, wherein the naturally curved second surface comprises one or more relief structures; wherein the naturally curved first surface is concave, and the naturally curved second surface is convex, and wherein the radius of curvature of the naturally curved first surface is within 15% of the radius of curvature of the naturally curved second surface.

[0037] The thin film has naturally curved first and second surfaces. In this context, the term "naturally curved" implies that the surfaces exhibit a natural curvature absent the exertion of some external force. The naturally curved first surface is a concave surface, which can have any suitable radius of curvature, depending on the desired curvature of the resulting thin film. The naturally curved second surface is a convex surface, which can have any suitable radius of curvature, depending on the desired curvature of the resulting thin film. In some embodiments, the two curved surfaces have similar radii of curvature, for example the radius of curvature of the naturally curved first surface is within 1%, or 2%, or 3%, or 5%, or 7%, or 10%, or 15%, or 20% of the radius of curvature of the naturally curved second surface.

[0038] The naturally curved second surface comprises one or more relief structures. In some embodiments, the naturally curved second surface comprises a plurality of relief structures, for example from 2 to 500, or from 5 to 200, or from 10 to 100 relief structures. The relief structures can be formed in any suitable way, e.g., by any suitable combination of recesses and extensions from the plane of the surface. In some embodiments, the relief structures are diffractive structures. The relief structures can be of any suitable size and shape. In some embodiments, the relief structures have a height ranging from 1 nm to 3 mm, or from 1 nm to 2 mm, or from 1 nm to 1 mm, or from 1 nm to 500 μm, or from 10 nm to 500 μm, or from 100 nm to 500 μm, or from 1 μm to 500 μm. In embodiments where the surface comprises a plurality of relief structures, the relief structures can be separated by any suitable distance. In some embodiments, one or more pairs of adjacent relief structures are separated by a distance ranging from 1 nm to 3 mm, or from 1 nm to 2 mm, or from 1 nm to 1 mm, or from 1 nm to 500 μm, or from 10 nm to 500 μm, or from 100 nm to 500 μm, or from 1 μm to 500 μm.

[0039] The relief structures can be formed onto the substrate in any suitable manner. In some embodiments, the relief structures are contiguous with the thin film, meaning that there is no interface between the relief structures and the rest of the film. In some such embodiments, the thin film, including the relief structures, is a continuous unit formed, for example, by using a mold that has the relief structures cut out of the mold.

[0040] The thin film can have any suitable appearance. In some embodiments, the thin film is transparent, meaning that it transmits at least 75%, or at least 80%, or at least 85%, or at least 90%, or at least 95%, or at least 97%, or at least 99% of visible light.

[0041] The thin film can have any suitable thickness. In some embodiments, the thin film has a thickness ranging from 1 μm to 1 mm, or from 10 to 500 μm, or from 50 to 200 μm. In some embodiments, the thickness is about 50 μm, or 100 μm, or 150 μm, or 200 μm, or 250 μm. The thin film, depending on its thickness, can have any suitable rigidity or flexibility. In some embodiments, however, the thin film is a relative flexible film.

[0042] In some aspects of the invention, the thin film can be employed in certain optical systems, such as electro-active systems. In such uses, it may be desirable to make a film having a certain refractive index. Thus, in some embodiments, the thin film has a refractive index of 1.5 to 1.8, or 1.6 to 1.7. In some embodiments, the thin film has a refractive index of 1.60, or 1.61. or 1.62, or 1.63, or 1.64, or 1.65, or 1.66, or 1.67, or 1.68, or 1.69, or 1.70, or 1.71, or 1.72.

[0043] Figure 4 shows at least one embodiment of such a thin film. The film 401 has a naturally curved shape and shows a number of relief structures 402. The films of the invention need not have uniform thickness, and can include films that exhibit thickness gradients and the like. Further, the relief structures 402 need not necessarily lie below the plane of the film itself. In some embodiments, the peaks in the relief structures can extend above the plane of the thin film.

[0044] In another aspect, the invention provides electro-active systems, comprising: (a) a curved substrate having a concave surface and a convex surface, wherein the concave surface is opposite the convex surface; (b) a thin film according to any of the embodiments described above disposed on the concave surface of the curved substrate such that the naturally curved second surface of the thin film faces the concave surface of the curved substrate.

[0045] The curved substrate has a concave surface and an opposing convex surface. The substrate can have any suitable shape. In some embodiments, the substrate has the general shape of a circle or an oval. In some embodiments, the electro-active system is designed to be disposed on the surface of a spectacle lens. In some such embodiments, the shape of the substrate can vary depending on the shape of the spectacle lenses onto which the electro-active system is to be disposed. In some embodiments where the substrate has a generally circular shape, the diameter can range from 3 to 20 mm, or from 5 to 15 mm.

[0046] The substrate can have any suitable appearance. In some embodiments, the substrate is transparent, meaning that it transmits at least 75%, or at least 80%, or at least 85%, or at least 90%, or at least 95%, or at least 97%, or at least 99% of visible light.

[0047] The curved substrate can be made of any suitable material. In some embodiments, the curved substrate is relatively rigid, and is composed of a material that provides such rigidity. For example, in some embodiments, the curved substrate can be a glass, or quartz, or a polymeric material, such as polycarbonate.

[0048] The substrate can have any suitable thickness. In some embodiments, the thin film has a thickness ranging from 100 μm to 5 mm, or from 300 μm to 2 mm, or from 500 μm to 1.5 mm. In some embodiments, the thickness is about 500 μm, or 700 μm, or 900 μm, or 1100 μm, or 1300 μm. In some embodiments, the substrate has a thickness that is sufficient to confer structural integrity and support the thin film that is disposed on the substrate.

[0049] In some embodiments, the electro-active system includes an adhesive layer disposed between the curved substrate and the thin film. In some such embodiments, the adhesive layer does not fill the entire space between the curved substrate and the thin film. In some embodiments, the adhesive layer forms a continuous line around the outer region of the space between the curved substrate and the thin film, thereby forming a cavity between the curved substrate and the thin film where no adhesive layer is present. In some embodiments, this cavity lies in the central region of the curved substrate. In some further embodiments, the cavity is a sealed cavity, where the cavity is sealed by a continuous line of the adhesive layer around the outer edge region of the space between the curved substrate and the thin film. In some embodiments, ad additional sealing material may be used, for example, to close any gaps. In some embodiments, one or more of the relief structures lie within the cavity.

[0050] The cavity can have any suitable dimensions. In some embodiments, the height of the cavity is greater than the height of the relief structures, for example, at least two times, or at least three times, or at least four times, or at least 5 times the height of the relief structures.

[0051] In some embodiments, the cavity is filled with an electro-active material. Electro-active materials are well known in the art, and include, but are not limited to, optical birefringent materials, such as liquid crystals. In some embodiments, the electro-active material only partially fills the cavity. In some other embodiments, the electro-active material fills the cavity, i.e., occupies at least 75%, or at least 80%, or at least 85%, or at least 90%, or at least 95% of the volume of the cavity.

[0052] In some embodiments, the electro-active system includes various electrical structures, such as electrical contacts and/or electrical wires. In some embodiments, these electrical structures are transparent electrical structures, meaning that they transmit at least 75%, or at least 80%, or at least 85%, or at least 90%, or at least 95%, or at least 97%, or at least 99% of visible light. These electrical structures can be made of any suitable transparent conductive material, such as indium tin oxide (ITO), conductive polymers, carbon nanotubes, or any mixtures thereof. Such structures can be disposed on the surfaces of the curved substrate and/or the thin film. These structures can be disposed on the surfaces by any suitable method, including but not limited to, various lithographic or printing methods.

[0053] Figure 7 depicts one embodiment of an electro-active system of the invention. In such embodiments, the electro-active system 700 includes a naturally curved thin film 701, a curved substrate 702, an adhesive layer 703 (which encircles the outer portion of the region between the curved substrate and the thin film), and a sealed cavity 704. In some embodiments, the sealed cavity contains an electro-active fluid.

[0054] In another aspect, the invention provides methods of making an electro-active system, comprising: (a) providing a curved substrate having a concave surface and a convex surface, wherein the concave surface is opposite the convex surface; (b) providing a thin film of any of the embodiments described herein; (c) securing the thin film to the curved substrate such that the naturally curved second surface of the thin film faces the concave surface of the curved substrate and forms a sealed cavity between the thin film and the curved substrate; and (d) injecting an electro-active material into the sealed cavity via an injection site in the thin film.

[0055] The method includes providing a curved substrate. The method is not limited to any particular type of curved substrate. In some embodiments, a curved substrate according to any of the embodiments can be used.

[0056] The method includes providing a thin film. The invention is not limited to any particular type of thin film. In some embodiments, a thin film according to any of the above embodiments can be used.

[0057] The method includes securing the thin film to the curved substrate. The securing can be carried out by any suitable means. In some embodiments, the securing comprises applying an adhesive, for example, to the curved substrate, the thin film, or both, and positioning them together. In some such embodiments, the adhesive is a photo-curable adhesive, such as a UV-curable adhesive. In such embodiments, the securing further comprises exposing the photo-curable adhesive to light, such as UV light, so as to cure the adhesive material.

[0058] The adhesive can be applied in any suitable manner, such as in one or more layers. In some embodiments, the adhesive layer does not fill the entire space between the curved substrate and the thin film. In some embodiments, the adhesive layer forms a continuous line around the outer region of the space between the curved substrate and the thin film, thereby forming a cavity between the curved substrate and the thin film where no adhesive layer is present. In some embodiments, this cavity lies in the central region of the curved substrate. In some further embodiments, the cavity is sealed by a continuous line of the adhesive layer around the outer edge region of the space between the curved substrate and the thin film. In some embodiments, ad additional sealing material may be used, for example, to close any gaps. In some embodiments, one or more of the relief structures lie within the cavity.

[0059] The cavity can have any suitable dimensions. In some embodiments, the height of the cavity is greater than the height of the relief structures, for example, at least two times, or at least three times, or at least four times, or at least 5 times the height of the relief structures.

[0060] The method includes injecting an electo-optical material into the sealed cavity. In some embodiments, the injecting is carried out in a manner such that the cavity is in a sealed state following the injecting. In some embodiments, where the injecting may leave a tiny aperture in the thin film at the injection site following the injecting, a sealant, such as a transparent sealant is applied to the injection site to re-seal the cavity. In other embodiments, the thin film is made of a material that is at least slightly gelatinous, such that it can re-seal itself at the injection site following the injection of the electro-active material. Such properties can be obtained by controlling the degree to which the film is cured, so as to retain some very slight amount of gel-like properties.

[0061] Any suitable electro-active materials can be used, including, but are not limited to, optical birefringent materials, such as liquid crystals. In some embodiments, the electro-active material only partially fills the cavity. In some other embodiments, the electro-active material fills the cavity, i.e., occupies at least 75%, or at least 80%, or at least 85%, or at least 90%, or at least 95% of the volume of the cavity.

[0062] In some embodiments, the method includes disposing various electrical structures, such as electrical contacts and/or electrical wires onto one or more surfaces of the curved substrate and/or the thin film. In some embodiments, these electrical structures are transparent electrical structures, meaning that they transmit at least 75%, or at least 80%, or at least 85%, or at least 90%, or at least 95%, or at least 97%, or at least 99% of visible light. These electrical structures can be made of any suitable transparent conductive material, such as indium tin oxide (ITO), conductive polymers, carbon nanotubes, or any mixtures thereof. These structures can be disposed on the surfaces by any suitable method, including but not limited to, various lithographic or printing methods.

[0063] Figure 8 depicts a flow diagram for a method of making an electro-active system. In such embodiments, the method includes: (a) providing a curved substrate having a concave surface and a convex surface, wherein the concave surface is opposite the convex surface 801; (b) providing a thin film of any of the embodiments described herein 802; (c) securing the thin film to the curved substrate such that the naturally curved second surface of the thin film faces the concave surface of the curved substrate and forms a sealed cavity between the thin film and the curved substrate 803; and (d) injecting an electro-active material into the sealed cavity via an injection site in the thin film 804.

[0064] In another aspect, the invention provides an optical substrate (e.g., a lens or a lens blank), where an electro-active system according to any of the above embodiments is disposed on a surface of the optical substrate. In some embodiments, the surface of the lens or lens blank onto which the electro-active system is disposed is a slightly curved surface, e.g., the convex surface on the outer side of a spectacle lens. In some embodiments, the side of the electro-active system having the thin film exposed is disposed against the surface of the optical substrate. The electro-active system can be secured to the lens or lens blank by any suitable means. In some embodiments, the electro-active system is secured to the lens or lens blank by means of an adhesive.

[0065] Figure 9 depicts one embodiment of the invention, where the electro-active system is disposed on an optical substrate. In such embodiments, the electro-active system includes a naturally curved thin film 901, a curved substrate 902, an adhesive layer 903 (which encircles the outer portion of the region between the curved substrate and the thin film), and a sealed cavity 904. In some embodiments, the sealed cavity contains an electro-active fluid. The electro-active system is disposed onto an optical substrate 905, such as a lens blank or a lens.

[0066] In another aspect, the invention provides a method of making a lens or lens blank comprising making an electro-active system according to any of the above embodiments, and disposing the electro-active system on lenses or lens blanks. In some embodiments, the surface of the lens or lens blank onto which the electro-active system is disposed is a slightly curved surface, e.g., the convex surface on the outer side of a spectacle lens. In some embodiments, the side of the electro-active system having the thin film exposed is disposed against the surface of the lens or lens blank. The electro-active system can be secured to the lens or lens blank by any suitable means. In some embodiments, the electro-active system is secured to the lens or lens blank by means of an adhesive. In some embodiments, the adhesive is a photo-curable adhesive, such as a UV-curable adhesive. In some such embodiments, the disposing comprises applying a photo-curable adhesive to the electro-active system and/or to the lens or lens blank, and exposing the photo-curable adhesive to light, such as UV light.

[0067] Figure 10 shows a flow diagram for making an optical substrate that includes an electro-active system. In the depicted embodiment, the method includes making an electro-active system according to any of the above embodiments 1001, and disposing the electro-active system on an optical substrate 1002.

Claims

1. A method of making an electro-active system, comprising:

    (a) providing a first substrate (101, 201) having a first surface, wherein the first substrate is composed of a water-soluble solid polymer comprising polyvinyl alcohol, a polyacrylamide, a polyacrylic acid, a polyisocyanate, a starch, or a cellulose;
    (b) providing a second substrate (102, 202) having a first surface, wherein the second substrate is composed of a solid material and the first surface of the second substrate comprises one or more relief structures (104, 204);
    (c) providing a curable liquid material (103, 203);
    (d) disposing the curable liquid material between the first surface of the first substrate and the first surface of the second substrate, wherein the first surface of the first substrate and the first surface of the second substrate are adjacent to each other;
    (e) curing the curable liquid material to form a polymeric film between the first surface of the first substrate and the first surface of the second substrate;
    (f) removing the first substrate from the polymeric film_by exposing the first substrate to an aqueous medium, thereby dissolving the first substrate;
    (f1) removing the polymeric film from the second substrate, so to obtain a polymeric thin film (701), comprising: a naturally curved first surface; and a naturally curved second surface disposed opposite the naturally curved second surface, wherein the naturally curved second surface comprises the one or more relief structures (104, 204);
    (g) providing a curved substrate (702) having a concave surface and a convex surface, wherein the concave surface is opposite the convex surface;
    (h) securing the polymeric thin film to the curved substrate such that the naturally curved second surface of the polymeric film faces the concave surface of the curved substrate and forms a sealed cavity (704) between the polymeric film and the curved substrate; and
    (i) injecting an electro-active material into the sealed cavity via an injection site in the polymeric film.

2. The method of claim 1, wherein the water-soluble polymer comprises polyvinyl alcohol.

3. The method of claim 1, wherein the first surface of the first substrate is a curved surface,

4. The method of claim 3, wherein the first surface of the second substrate is a curved surface.

5. The method of claim 4, wherein the radius of curvature of the first surface of the first substrate is within 15% of the radius of curvature of the first surface of the second substrate.

6. The method of claim 5, wherein one of the first surfaces is a convex surface and the other is a concave surface.

7. The method of claim 1, wherein the curable liquid material is a liquid monomer, a liquid oligomer, or a mixture thereof.

8. The method of claim 1, wherein the one or more relief structures are inverted diffractive structures.

9. The method of claim 8, wherein the one or more relief structures have a height that ranges from 1 nm to 500 μm.

10. The method of claim 1, wherein the first surface of the second substrate comprises a plurality of relief structures, and wherein one or more adjacent pairs of relief structures are separated by a distance ranging from 1 nm to 500 μm.

11. The method of claim 1, wherein the disposing the curable liquid material between the first surface of the first substrate and the first surface of the second substrate comprises separating the first surface of the first substrate from the first surface of the second substrate by a distance of 1 μm to 1 mm.

12. The method of claim 1, wherein the electro-active material comprises liquid crystals.

13. The method of claim 1, wherein the electro-active system is secured to a lens or a lens blank.

14. The method of claim 1, wherein the electro-active system has a curved substrate having a concave surface and a convex surface, wherein the concave surface is opposite the convex surface; and the polymeric film is disposed to face the concave surface of the curved substrate.

Patentansprüche

1. Verfahren zur Herstellung eines elektroaktiven Systems, umfassend:

   (a) Bereitstellen eines ersten Substrats (101, 201) mit einer ersten Oberfläche, wobei das erste Substrat aus einem wasserlöslichen festen Polymer besteht, das Polyvinylalkohol, ein Polyacrylamid, eine Polyacrylsäure, ein Polyisocyanat, eine Stärke oder eine Cellulose aufweist;
   (b) Bereitstellen eines zweiten Substrats (102, 202) mit einer ersten Oberfläche, wobei das zweite Substrat aus einem festen Material besteht und die erste Oberfläche des zweiten Substrats eine oder mehrere Reliefstrukturen (104, 204) aufweist;
   (c) Bereitstellen eines härtbaren flüssigen Materials (103, 203);
   (d) Anordnen des härtbaren flüssigen Materials zwischen der ersten Oberfläche des ersten Substrats und der ersten Oberfläche des zweiten Substrats, wobei die erste Oberfläche des ersten Substrats und die erste Oberfläche des zweiten Substrats aneinander liegen;
   (e) Härten des härtbaren flüssigen Materials, um einen Polymerfilm zwischen der ersten Oberfläche des ersten Substrats und der ersten Oberfläche des zweiten Substrats zu bilden;
   (f) Entfernen des ersten Substrats von dem Polymerfilm durch Aussetzen des ersten Substrats eines wässrigen Mediums, wodurch das erste Substrat gelöst wird;
   (fl) Entfernen des Polymerfilms von dem zweiten Substrat, um einen polymeren dünnen Film (701) zu erhalten, aufweisend: eine natürlich gekrümmte erste Oberfläche; und eine natürlich gekrümmte zweite Oberfläche, die gegenüber der natürlich gekrümmten zweiten Oberfläche angeordnet ist, wobei die natürlich gekrümmte zweite Oberfläche die eine oder die mehreren Reliefstrukturen (104, 204) aufweist;
   (g) Bereitstellen eines gekrümmten Substrats (702) mit einer konkaven Oberfläche und einer konvexen Oberfläche, wobei die konkave Oberfläche gegenüber der konvexen Oberfläche liegt;
   (h) Sichern des polymeren dünnen Films an dem gekrümmten Substrat, so dass die natürlich gekrümmte zweite Oberfläche des polymeren Films der konkaven Oberfläche des gekrümmten Substrats zugewandt ist und einen geschlossenen Hohlraum (704) zwischen dem polymeren Film und dem gekrümmten Substrat bildet; und
   (i) Injizieren eines elektroaktiven Materials in den geschlossenen Hohlraum über eine Injektionsstelle in dem Polymerfilme.

2. Verfahren nach Anspruch 1, wobei das wasserlösliche Polymer Polyvinylalkohol aufweist.

3. Verfahren nach Anspruch 1, wobei die erste Oberfläche des ersten Substrats eine gekrümmte Oberfläche hat.

4. Verfahren nach Anspruch 3, wobei die erste Oberfläche des zweiten Substrats eine gekrümmte Oberfläche hat.

5. Verfahren nach Anspruch 4, wobei der Krümmungsradius der ersten Oberfläche des ersten Substrats innerhalb von 15% des Krümmungsradius der ersten Oberfläche des zweiten Substrats liegt.

6. Verfahren nach Anspruch 5, wobei eine der ersten Oberflächen eine konvexe Oberfläche und die andere eine konkave Oberfläche ist.

7. Verfahren nach Anspruch 1, wobei das härtbare flüssige Material ein flüssiges Monomer, ein flüssiges Oligomer oder eine Mischung davon ist.

8. Verfahren nach Anspruch 1, wobei die eine oder die mehreren Reliefstrukturen invertierte diffraktive Strukturen sind.

9. Verfahren nach Anspruch 8, wobei die eine oder die mehreren Reliefstrukturen eine Höhe aufweisen, die von 1 nm bis 500 μm reicht.

10. Verfahren nach Anspruch 1, wobei die erste Oberfläche des zweiten Substrats eine Vielzahl von Reliefstrukturen aufweist, und wobei ein oder mehrere aneinander liegende Paare von Reliefstrukturen durch einen Abstand von 1 nm bis 500 μm getrennt sind.

11. Verfahren nach Anspruch 1, wobei das Anordnen des härtbaren flüssigen Materials zwischen der ersten Oberfläche des ersten Substrats und der ersten Oberfläche des zweiten Substrats das Trennen der ersten Oberfläche des ersten Substrats von der ersten Oberfläche des zweiten Substrats um einen Abstand von 1 μm bis 1 mm aufweist.

12. Verfahren nach Anspruch 1, wobei das elektroaktive Material Flüssigkristalle aufweist.

13. Verfahren nach Anspruch 1, wobei das elektroaktive System an einer Linse oder einem Linsenrohling gesichert ist.

14. Verfahren nach Anspruch 1, wobei das elektroaktive System ein gekrümmtes Substrat mit einer konkaven Oberfläche und einer konvexen Oberfläche aufweist, wobei die konkave Oberfläche der konvexen

Oberfläche gegenüberliegt; und der Polymerfilm so angeordnet ist, dass er der konkaven Oberfläche des gekrümmten Substrats gegenüberliegt.

Revendications

1. Un procédé de fabrication d'un système électro-actif, comprenant :

(a) le fait de prévoir un premier substrat (101, 201) ayant une première surface, le premier substrat étant composé d'un polymère solide hydrosoluble comprenant un alcool polyvinylique, un polyacrylamide, un acide polyacrylique, un polyisocyanate, un amidon ou une cellulose ;
(b) le fait de prévoir un deuxième substrat (102, 202) ayant une première surface, le deuxième substrat étant composé d'un matériau solide et la première surface du deuxième substrat comprenant une ou plusieurs structures en relief (104, 204);
(c) le fait de prévoir une matière liquide durcissable (103, 203) ;
(d) le fait de disposer le matériau liquide durcissable entre la première surface du premier substrat et la première surface du deuxième substrat, la première surface du premier substrat et la première surface du deuxième substrat étant adjacentes l'une de l'autre ;
(e) le fait d'opérer un durcissement du matériau liquide durcissable pour former un film polymère entre la première surface du premier substrat et la première surface du deuxième substrat ;
(f) le fait d'enlever le premier substrat du film polymère en exposant le premier substrat à un milieu aqueux, dissolvant de ce fait le premier substrat ;
(fl) le fait d'enlever le film polymère du deuxième substrat, de manière à obtenir un film mince polymère (701), comprenant : une première surface naturellement courbée ; et une deuxième surface naturellement courbée disposée à l'opposé de la deuxième surface naturellement courbée, la deuxième surface naturellement courbée comprenant lesdites une ou plusieurs structures en relief (104, 204);
(g) le fait de fournir un substrat courbe (702) ayant une surface concave et une surface convexe, la surface concave étant opposée à la surface convexe ;
(h) le fait de fixer le film mince polymère sur le substrat courbé de telle sorte que la deuxième surface naturellement courbée du film polymère soit tournée vers la surface concave du substrat courbé et forme une cavité (704) fermée de façon étanche entre le film polymère et le substrat courbé ; et
(i) le fait d'injecter un matériau électro-actif dans la cavité fermée via un site d'injection dans le film polymère.

2. Le procédé selon la revendication 1, dans lequel le polymère soluble dans l'eau comprend de l'alcool polyvinylique.

3. Le procédé selon la revendication 1, dans lequel la première surface du premier substrat est une surface courbe.

4. Le procédé selon la revendication 3, dans lequel la première surface du deuxième substrat est une surface courbe.

5. Le procédé selon la revendication 4, dans lequel le rayon de courbure de la première surface du premier substrat est à moins de 15% du rayon de courbure de la première surface du deuxième substrat.

6. Le procédé selon la revendication 5, dans lequel une des premières surfaces est une surface convexe et l'autre est une surface concave.

7. Le procédé selon la revendication 1, dans lequel le matériau liquide durcissable est un monomère liquide, un oligomère liquide ou un mélange de ceux-ci.

8. Le procédé selon la revendication 1, dans lequel lesdites une ou plusieurs structures en relief sont des structures diffractives inversées.

9. Le procédé selon la revendication 8, dans lequel lesdites une ou plusieurs structures en relief ont une hauteur qui varie de 1 nm à 500 μm.

10. Le procédé selon la revendication 1, dans lequel la première surface du deuxième substrat comprend une pluralité de structures en relief, et dans lequel une ou plusieurs paires adjacentes de structures en relief sont séparées par une distance allant de 1 nm à 500 μm.

11. Le procédé selon la revendication 1, dans lequel le fait de disposer le matériau liquide durcissable entre la première surface du premier substrat et la première surface du deuxième substrat comprend le fait de séparer la première surface du premier substrat de la première surface du deuxième substrat sur une distance de 1 μm à 1 mm.

12. Le procédé selon la revendication 1, dans lequel la matière électro-active comprend des cristaux liquides.

13. Le procédé selon la revendication 1, dans lequel le système électro-actif est fixé à une lentille ou à une

ébauche de lentille.

14. Le procédé selon la revendication 1, dans lequel le système électro-actif a un substrat courbé ayant une surface concave et une surface convexe, la surface concave étant opposée à la surface convexe ; et le film polymère est disposé de façon à être tourné vers la surface concave du substrat courbe.

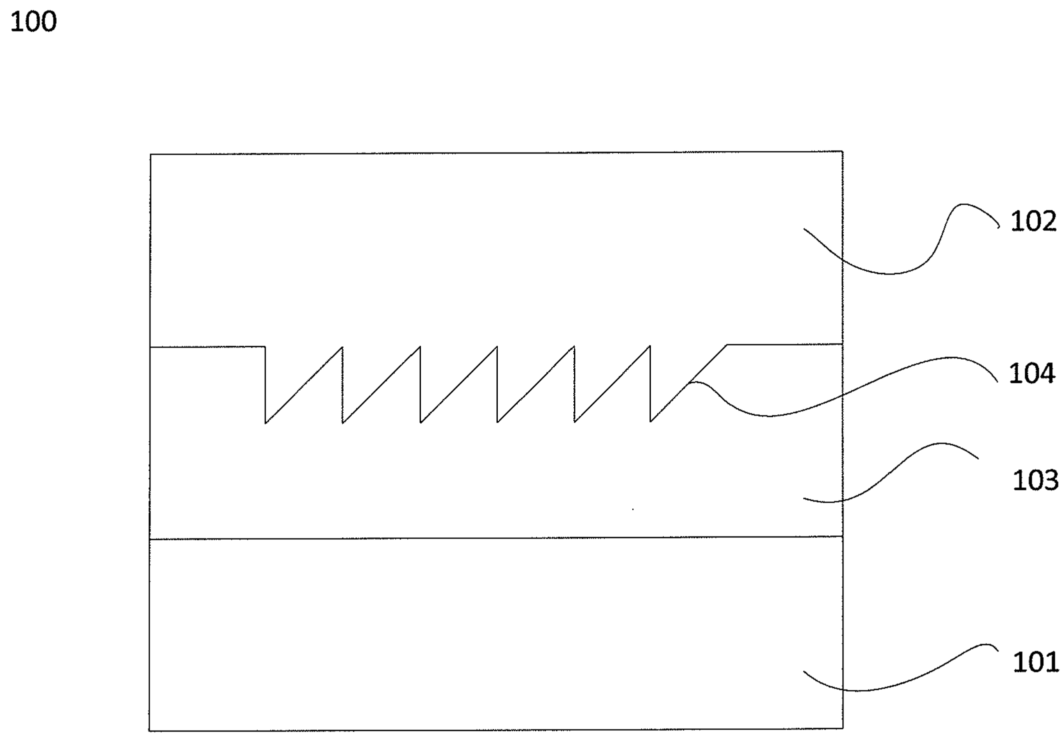

FIGURE 1

200

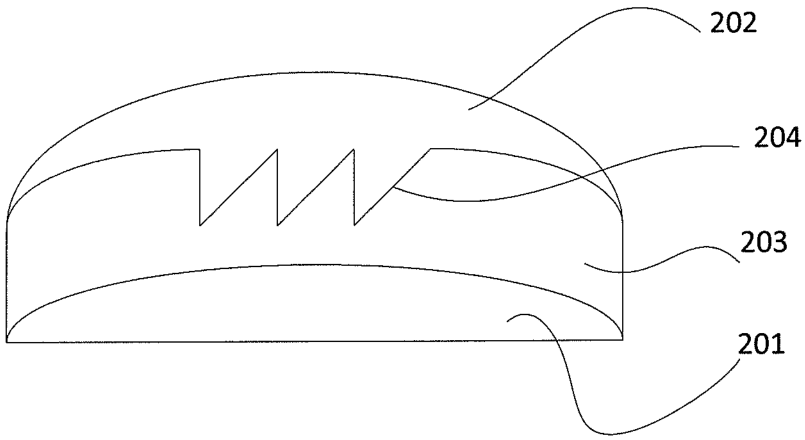

FIGURE 2

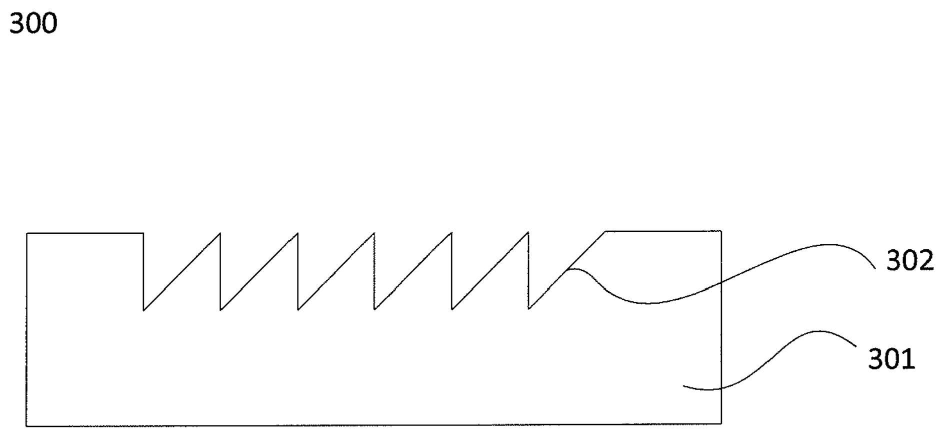

FIGURE 3

400

FIGURE 4

500

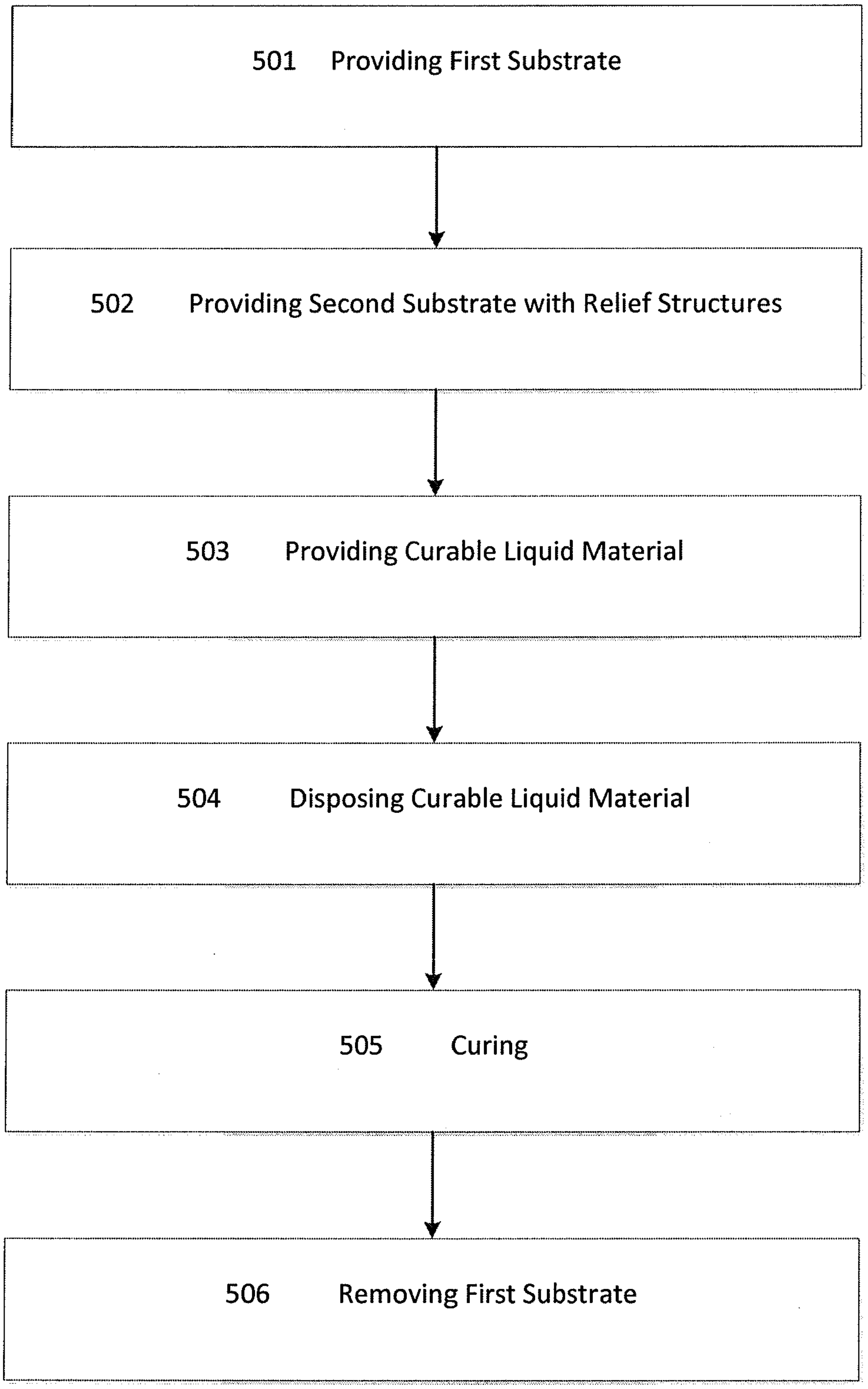
501 Providing First Substrate
502 Providing Second Substrate with Relief Structures
503 Providing Curable Liquid Material
504 Disposing Curable Liquid Material
505 Curing
506 Removing First Substrate

FIGURE 5

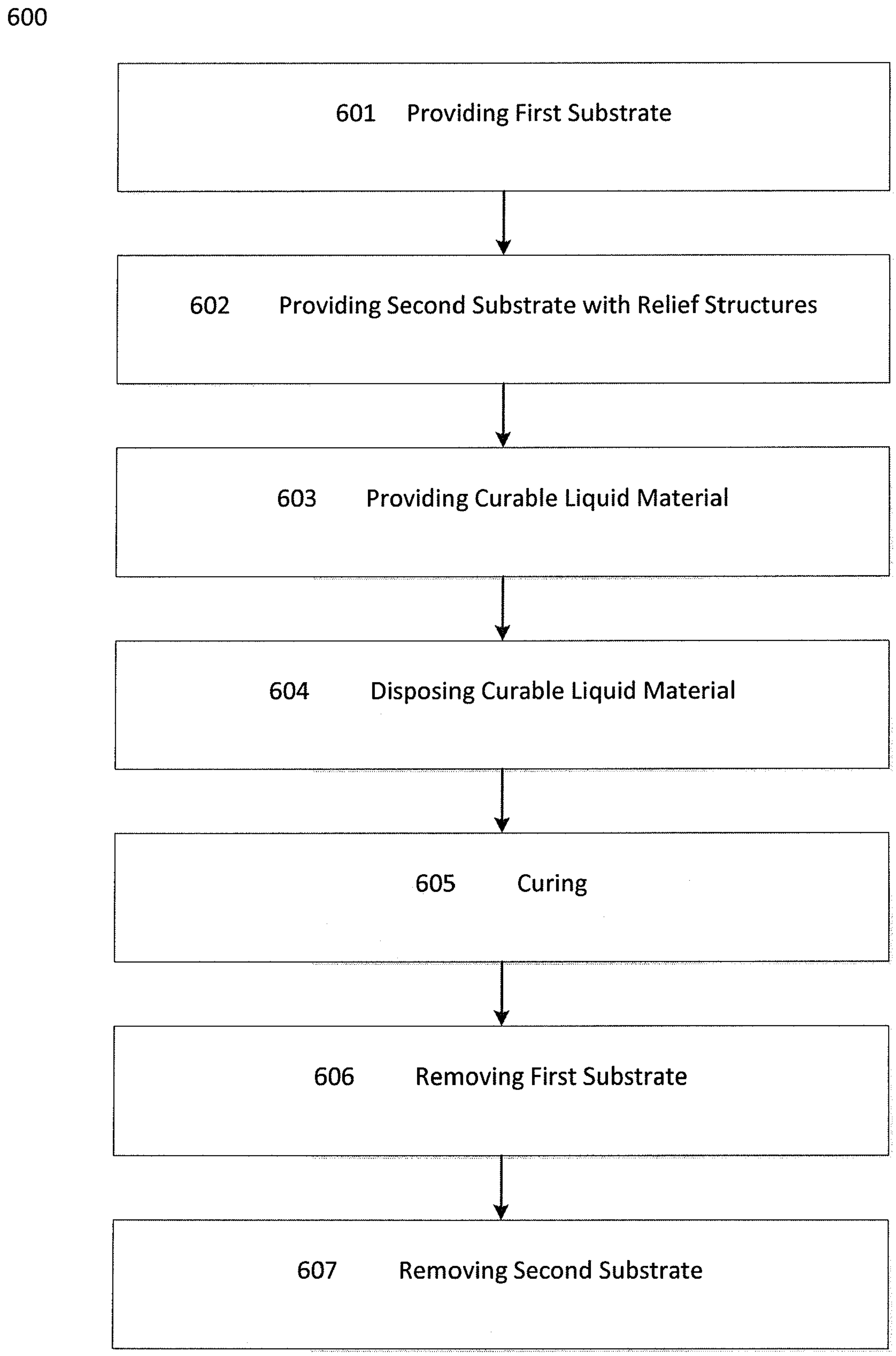
600
601 Providing First Substrate
602 Providing Second Substrate with Relief Structures
603 Providing Curable Liquid Material
604 Disposing Curable Liquid Material
605 Curing
606 Removing First Substrate
607 Removing Second Substrate

FIGURE 6

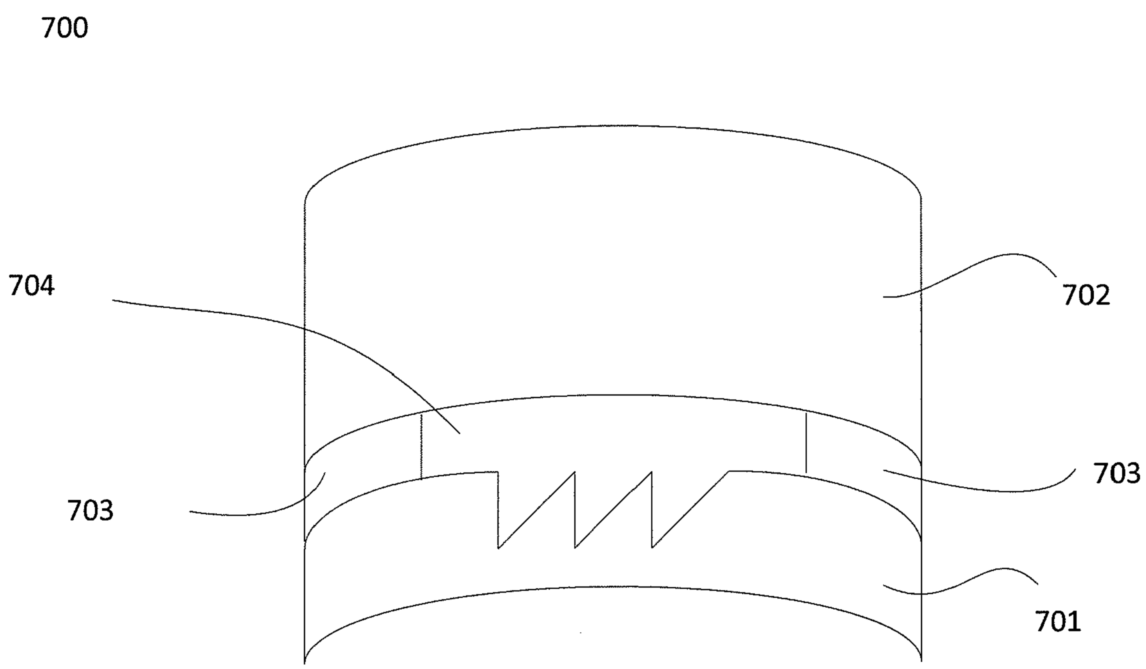

FIGURE 7

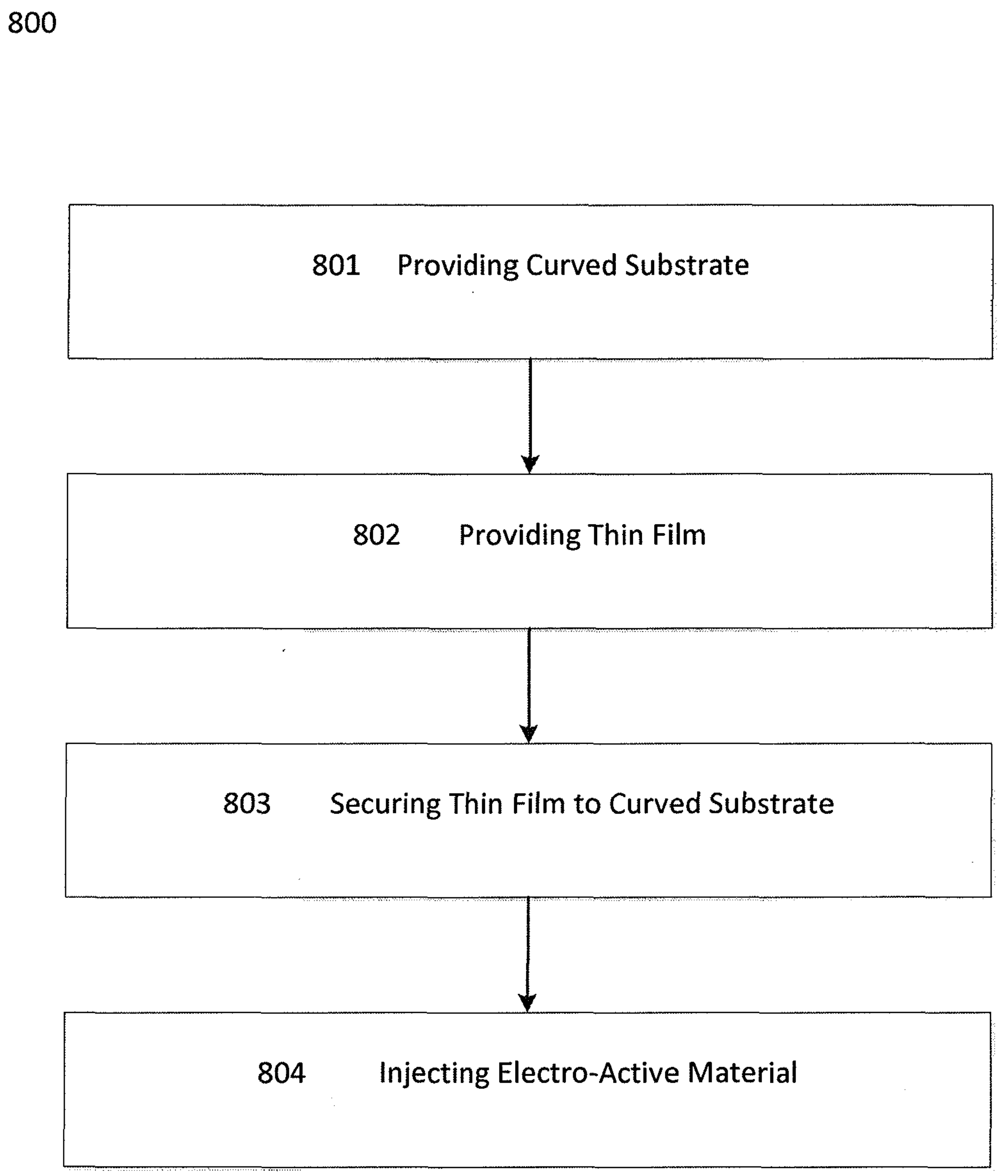
800
801 Providing Curved Substrate
802 Providing Thin Film
803 Securing Thin Film to Curved Substrate
804 Injecting Electro-Active Material

FIGURE 8

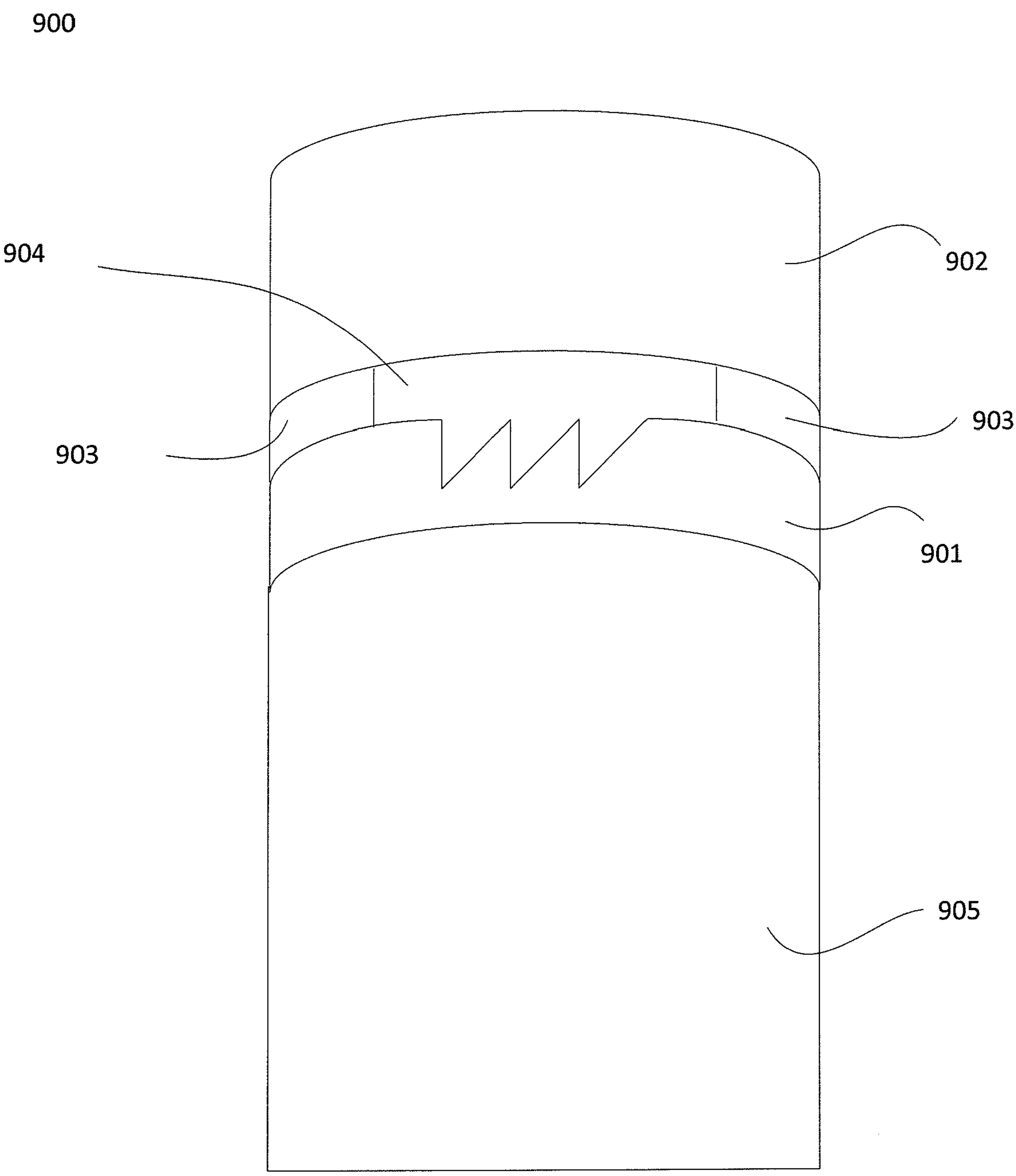

FIGURE 9

1000

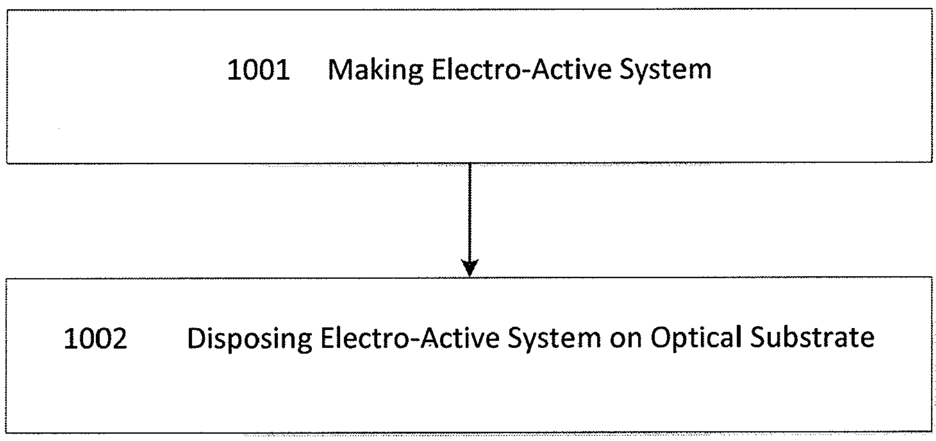

FIGURE 10

REFERENCES CITED IN THE DESCRIPTION

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